RETROFITTING GAS TURBINES WITH COMPUTER CONTROL

by

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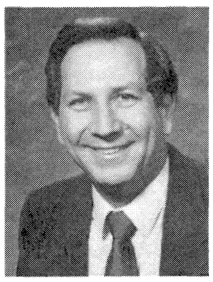

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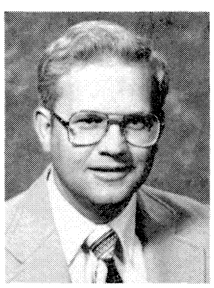

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ABSTRACT

Retrofitting gas turbines with microprocessor based controls has improved reliability and performance in the areas of speed control, temperature control, and load control. The rationale behind control system retrofits is described. Installation problems and benefits derived from retrofits also is discussed.

The details of six heavy duty single-shaft gas turbine retrofits are presented. These turbines drive both process compressors and electric generators at the Amoco Oil Company, Texas City refinery. Turbomachinery control system retrofits can improve reliability and decrease operating costs.

INTRODUCTION

Most petrochemical plants and electric utilities utilize gas turbines to drive rotating equipment critical to plant operation. Many of these turbines are controlled by systems having high maintenance costs and low operating reliability. The low operating reliability is usually a greater economic factor than the high maintenance costs.

The decision was made to improve the operating reliability of six heavy duty single-shaft gas turbines by retrofitting the control systems. The first retrofit was started in 1969, with an analog computer replacing a hydraulic-mechanical system. The computer allowed operation closer to the permissible blade temperature limits, while at the same time providing better protection from overfiring. This resulted in better utilization of machine capacity, while ensuring maximum blade life, an item of considerable cost.

The latest control retrofit was completed in March 1986 and consisted of replacing an analog control system with a digital redundant system. This provided better speed control, improved reliability, and enhanced troubleshooting capabilities.

A history of the Amoco gas turbine retrofits and applications is shown on Table 1.

PROBLEMS WITH HYDRAULIC-MECHANICAL CONTROLS

There were various problems associated with hydraulic-mechanical controls. Many hours, and in some cases days, were required to bring the turbine online, due to problems in the control system. The problems associated with the flyball governor were binding linkage, hydraulic leaks, backlash, and wear points creating unstable speed control. The turbine could never be run at maximum efficiency because the temperature controller was unable to hold the temperature within tight enough

Table 1. History of Gas Turbine Retrofits and Their Application.

Application	*Turbine Description*	*System to Retrofit*	*Date Turbine Installed*	*Retrofit*	*Retrofit Installed*
Hydrogen Makeup Gas Compressor	17,400 hp gas fired turbine with an 8,000 hp steam helper turbine.	HMC	1968	Turbo-Tronic Analog	1971
Hydrogen Makeup Gas Compressor	17,400 hp gas fired turbine with an 8,000 hp steam helper turbine.	Turbo-Tronic Analog	1968	TT2000 Digital	1981
Turbogenerator	12,500 kw gas fired turbine with a 290 hp diesel engine.	HMC	1967	TT2000 Digital	1984
Turbogenerator	15,250 kwgas fired turbine with a 265 hp diesel engine.	HMC	1967	TT2000 Digital	1983
Turbogenerator	13,750 kw gas fired turbine with a 3,686 hp steam helper turbine	HMC	1978	TT2000 Digital	1983
Air Compressor	19,950 hp gas fired turbine with a 10,000 hp steam helper turbine	HMC	1962	Turbo-Tronic Analog	1973
Air Compressor	19,950 hp gas fired turbine with a 10,000 hp steam helper turbine	Turbo-Tronic Analog	1962	TS500 Digital Redundant	1986
Wet Gas Compressor	19,950 hp gas fired turbine with a 8,490 hp steam helper turbine	HMC	1962	Turbo-Tronic Analog	1969
Wet Gas Compressor	19,950 hp gas fired turbine with an 8,490 hp steam helper turbine.	Turbo-Tronic Analog	1962	TS500 Digital Redundant	1986

limits to prevent overfiring the turbine. Therefore, the turbine had to run at a lower temperature set point.

The gas turbine overspeed bolt also proved to be unreliable. Thus, the turbine could not be run at maximum governor speed. The bolt itself and the latching mechanism were not designed for accuracy greater than plus or minus two percent [1]. If the overspeed bolt needed adjustment, the turbine had to be shut down. Then after the turbine had cooled, a minor disassembly was required in order to adjust the bolt. This usually took two to four hours, and there was no guarantee it would be adjusted correctly.

When the turbine tripped, there was a low probability of finding the cause, unless some device had physically broken. In addition, adjustment of mechanical linkages was extremely difficult and time consuming. Because of these limitations, the first gas turbine was retrofitted.

IMPROVING THE CONTROL SYSTEM

Fear of change can be a retardant to any new installation. This was found not to be the case. Employees combined their "old" expertise with the new technology, and quickly became proficient in maintaining and operating the equipment.

Hydraulic-Mechanical Control to Analog

The first retrofit was a hydraulic-mechanical, to analog control system in 1969. The turbine was driving a wet gas compressor. This retrofit eliminated problems associated with the hydraulic-mechanical controls. Analog controls are very reliable and have many benefits over hydraulic-mechanical systems. Wiring schematic diagrams and circuits could be understood by the average technician. Calibration was much simpler and more precise. A simulation of the complete startup of the turbine was now possible.

In upgrading to an analog system, the engineers had to determine what parts of the existing system could still be utilized. The company did not want to eliminate any components that performed well, proved to be reliable, and would interface with the new system.

The analog control system outputs electronic control signals for valve operation. These signals are then changed to pneumatic or hydraulic at the actuator. Speed of response is critical. Valve actuators should respond rapidly to changes in input signal. The experience has been that piston-type actuators give the best response for this application.

The installation on the turbine deck was relatively simple. The only limitations were lack of space and the surrounding environment (heat). Some of the problems encountered were actuator mountings, and sloppy connecting linkages.

Each actuator mounting is unique to the turbine, therefore each must be engineered differently. The mounting brackets must be custom built for each actuator. Since control gets sloppy due to wear of connecting linkages, rod end bearings are replaced during every major turnaround.

The intentions were not to install a complete control system, only improve on the existing one. The original assignment was to upgrade the temperature controller. The existing system used a Taylor Sensaire thermal system for temperature measurement. It was replaced with thermocouples, which greatly improved stability.

Another area of concern was speed control. How to establish a good speed feedback signal, and where to locate this on the existing machine was the next assignment. The existing flyball control scheme left a lot to be desired in regard to dependability and tight control. Therefore, a counter wheel was installed on the outboard shaft of the steam turbine and a magnetic pickup was used to sense speed. This eliminated the flyballs, gear reduction drives, stubs, and overhung shaft [1].

A pneumatic actuator was attached to the end of the gas control valve lever to be used as the operator to the pilot valve. This eliminated the pre-pilot valve (spool piece) associated with the flyball governor, thus improving control response time. A pneumatic actuator was also needed on the steam rack of the helper turbine.

A built-in advantage of this new control scheme was a more reliable overspeed trip system. The engineers no longer relied on just the overspeed bolts from the steam turbine, and the gas turbine. With the magnetic speed pickup, and the electronic control circuits, Amoco had a more precise, and dependable overspeed system. The accuracy of the electronic speed circuit was within plus or minus 0.1 percent.

Three completed hydraulic-mechanical to analog retrofits are shown on Table 1.

Analog to Digital

While there were tremendous improvements in control and reliability, the analog systems had inherent problems. When the control strategy changed, circuit modification became necessary. This required a significant amount of expertise in the systems, and added many uncertainties to the resultant reliability. This was always a concern when improvements were initiated.

Trending on analog systems was limited to recorders. On many occasions after an unplanned trip, the recorders would be out of paper. Thus, no trending information would be available. In addition, recorders were difficult to reconfigure. If more trending points were required, additional hardware had to be purchased.

Analog meters were also a constant source of error. They could give a variety of readings depending on from what angle the meter was observed. Static electricity would cause the meters to give erroneous readings. If additional data was required, a new meter would have to be installed.

Being able to rely on accurate calibration is an important feature of any control system. Calibration is usually the biggest problem with analog systems.

With digital technology, the previous mentioned problems are virtually eliminated. The digital systems run on computer programs. To change calibration, controller tuning, or other parameters, all that has to be done is program modification. Some systems are designed so these changes can be made by the end user.

In 1981, the first digital retrofit was performed. After ten years of service, the third hydraulic-mechanical retrofit (an analog control system on a hydrogen makeup gas compressor) was replaced. This decision was made due to the age of the control system, decreased reliability of the field wiring, and breakthroughs in new digital computer technology. Digital control systems had been around for years, but cost, physical size, reliability, and response time made their use impractical.

Since the existing control system was electronic, there were minimal modifications needed on the turbine. While the analog system required only one speed probe, the digital system required four. This meant modifying the speed probe mountings on both the steam and gas turbines. The digital system also brought new solutions to old problems, such as the effect of lightning strikes in close proximity to the thermocouple wire. The lightning strikes caused the low voltage signals from the thermocouples to be driven up scale, causing an erroneous high temperature trip. With the digital system, the program was modified to interrogate the thermocouple signal for two seconds, thus eliminating a false trip. Long distance communication runs between computers located in the control room and on the compressor deck also caused problems. The digital signals were susceptible to induced voltages from starting electric motors and, lightning strikes. This problem was remedied by the use of modems.

Another particular problem was a poorly designed counter wheel. The company decided that during this installation, the existing ten tooth counter wheel would be changed to a thirteen inch, sixty tooth counter. The required tooth cut was not specified, and a wheel with a square cut tooth was installed. This produced a distorted speed signal which fooled the electronic circuitry and caused erroneous speed signals. The tooth cut should have been a gear cut, with specifications given as shown in Figure 1. The turbine retrofit was completed, and the process unit put back on line in February 1981.

Hydraulic-Mechanical to Digital

Because of the outstanding performance of the digital control system on the hydrogen makeup gas compressor drive, the decision was made to retrofit three power station gas turbines with digital controls. Two of the gas turbines were driving 15.6 megawatt generators, and were using diesel engines as starters. The third was driving an 18.7 megawatt generator, and used a steam helper turbine. Since these were turbogenerators, new software packages had to be developed due to the associated power generation equipment.

A difference from previous retrofits was that a variable control oil system had replaced the flyball governor. Like the flyball governor, this pump and existing hardware were removed to make way for the digital controls. With the exception of the diesel engine, the ratcheting mechanism, and the variable con-

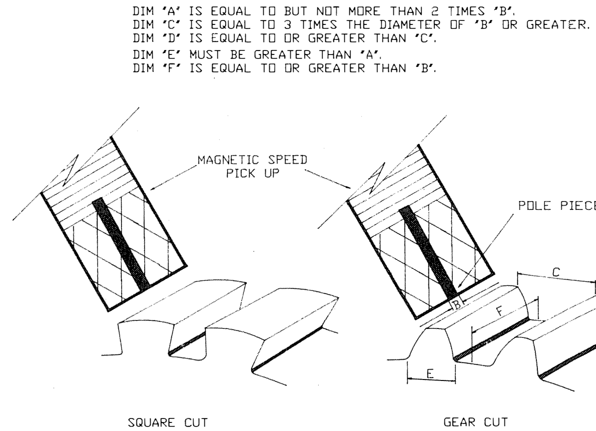

Figure 1. Magnetic Speed Pickup and Counter Wheel Profile.

trol oil; the retrofits required the same hardware changes as those for the three previous analog retrofits.

A hydraulic-mechanical control console is shown in Figure 2 and a digital control console is shown in Figure 3.

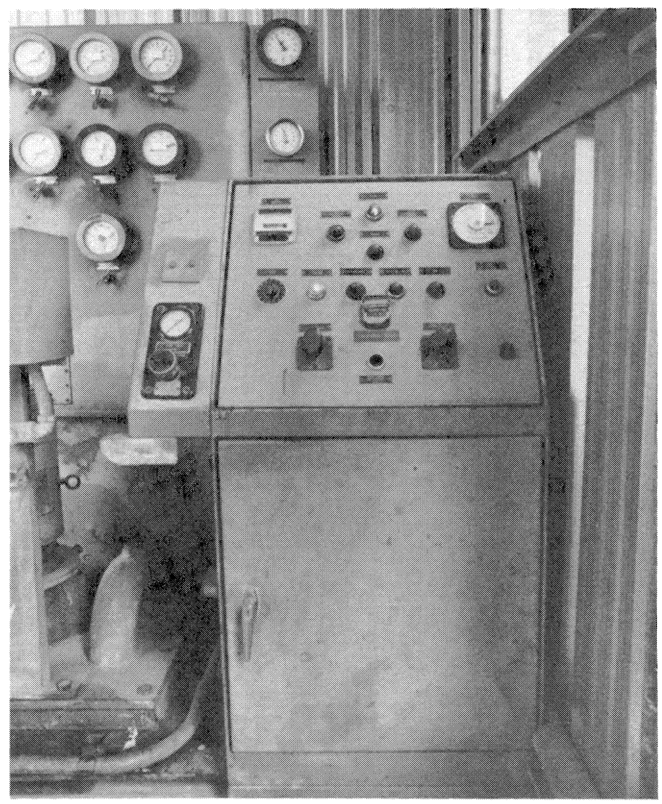

Figure 2. Hydraulic-Mechanical Control Console.

Analog To Redundant Digital

The latest retrofit was completed in March 1986. The company chose to retrofit two heavy duty single-shaft gas turbines from analog to redundant digital control. After sixteen years (a wet gas compressor drive), and thirteen years (an air compressor drive) of service, the analog control systems were retired.

The advantages of a redundant control system include not having a turbine shut down due to control board failure, failed field contact, or defective transmitter. Redundancy keeps the turbine running.

What is redundancy? How does it work? Redundancy adds another complete control system to the existing one. Any time

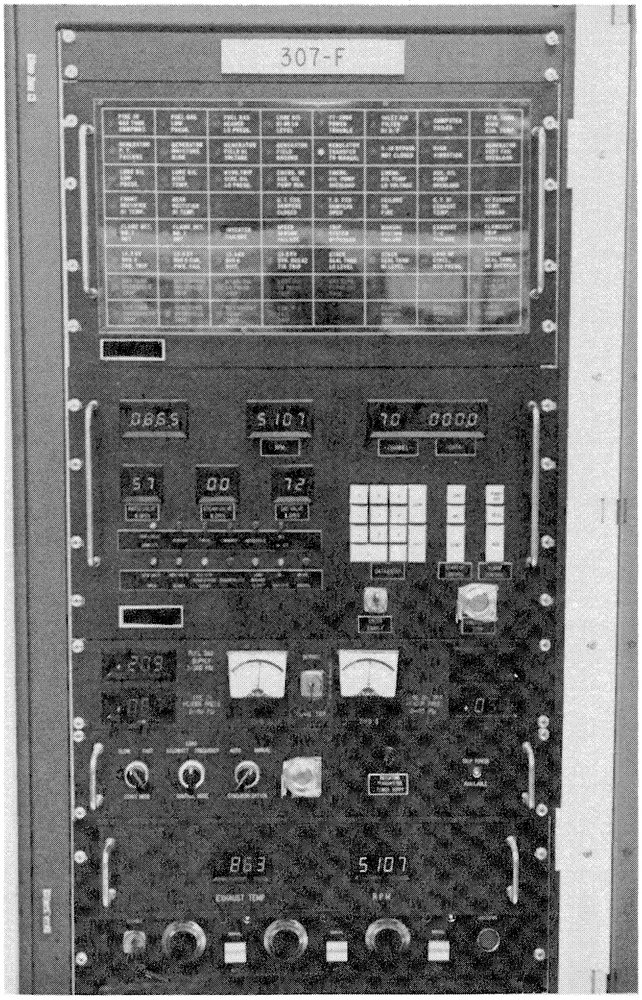

Figure 3. Digital Control Console.

one system fails, the second control system immediately takes over. A failure alarm will inform personnel that one system has failed, and it may be repaired while the healthy system is controlling the turbine. When field devices, such as fuel gas pressure and axial air pressure transmitters are made redundant, the same advantage exists.

Redundancy is also used in alarm and trip contacts. Instead of one alarm and one trip contact, a redundant system has two trip contacts and one alarm contact. The logic is that two out of three contacts in the proper sequence are needed to trip the turbine. The logic is shown on Table 2.

Table 2. Field Contact Trip Logic for Redundant Controls.

First Contact Received	*Second Contact Received*	*Third Contact Received*	*Turbine Action*
Alarm	None	None	No Trip
Trip	None	None	No Trip
Alarm	Trip	None	Trip
Trip	Trip	None	Trip
Trip	Alarm	None	No Trip
Trip	Alarm	Trip	Trip
Alarm	Trip	Trip	Trip
Trip	Trip	Alarm	Trip

The control system should have voting logic to trip. This means that even though only one computer is controlling the turbine, both the operating and backup computers must agree the trip is real before initiating a shutdown.

Another key area for redundancy is the controller power source. A power failure would disable the controller, therefore a source of uninterruptable power is needed.

In order to take full advantage of a redundant control system, a device failure needs to be repaired at the next opportune time, or the integrity of the control system will be jeopardized.

SEQUENCE OF A RETROFIT

The first step in the retrofit project was to classify the job into three categories. These were control system (speed, and temperature), safety (machine and process protection), and auxiliary systems (helper turbine, lube oil system, alarm notification, and trending). The needs and wants of each category were listed. During the planning stage, input was gathered from the operating personnel who were going to use the system and the instrument technicians who were going to maintain it. The next step was to decide what the control system should do. A system was needed which could be modified at a later date. Even though gas turbines are similar, there are different ways to start and operate them.

Purchasing the System

What type of equipment should be bought, and from whom should it be purchased? First, find out who manufactures control system retrofits for the particular turbine. Next, check the manufacturers' experience level in this field. This could make a big difference in continual modifications during installation, startup, and operation of the turbine. Finally, talk to people who have purchased a similar system. Ask what type or how many problems were encountered during installation, startup, and operation. See how helpful and knowledgeable the service people were during these times.

A general specification was developed describing what the controller was to do. Once a manufacturer was selected, then detailed specifications were written. The requirements for starting the turbine were listed. These included the slow roll speed, length of purge time required, speed at which to purge, and when to fire.

The company wanted the computer to display reminders on the CRT—i. e., "open the vent valve." In addition, several permissives had to be satisfied before firing. The fuel gas pressure needed to be in the proper range. The remote speed set point had to be lowered to minimum governor. The air compressor bypass valves needed to be opened. Other considerations were how long the spark plugs should stay energized during the firing mode, and how far open the gas valve needed to be before firing.

If the turbine does not fire, the computer closes the stop valve, gas control valve, and automatically restarts the purge. Certain steps of the startup sequence can be automated. For example, the fuel vent and the compressor bypass valves can be made to open or close, automatically.

When the turbine is fired, turbine speed and gas valve position during warmup had to be decided. After the warm up period, the turbine was allowed to automatically accelerate to a minimum speed. On one turbine, all criticals were between 1900 and 3800 rpm. The engineers chose to accelerate at a rapid rate and halt the firing sequence at a speed of 4,000 rpm. The air compressor bypass valves are then manually closed and the turbine is allowed to accelerate to a minimum governor speed of 4,280 rpm.

The control system does much more than just start the turbine. While the turbine is running, items like firing temperature, turbine bias, and speed are monitored and kept in range. It also monitors alarm points, decides what to do if a control thermocouple burns out, and at what point to trip the turbine.

Installation Planning

The next detail is deciding who should install the control system. Should the work be contracted, or should it be done in-house? This decision must be given careful consideration. The installation is the most important part of the retrofit.

User installation results in expertise in debugging, and maintaining the system. If a user has the capability and the time, company people should perform the installation. The company engineers made the decision to perform the installation using their own people. The first step was to assemble a team. The team consisted of people who knew how to accomplish the various tasks which included control system, field devices, installation, engineering and planning. Next a plan and time schedule was determined. The plan and time schedule was posted and continuously updated. This allowed awareness by everyone involved in the project from technicians to upper management of the progress.

The digital controls manufacturer chosen was located in the vicinity of the refinery, which facilitated a favorable relationship while the system was being built. Users should work closely with the manufacturer, keeping abreast of system developments. The users should learn how the system works so there will be little doubt when the system becomes their responsibility. Be certain the system performs as specified before it is accepted. If changes are to be made, whether at the users or manufacturer's request, make sure they are made before delivery and are documented.

The manufacturer may be able to provide a turbine simulator, which will be very useful for system check out, and will enhance operator training. After the control system arrives, the electronics should be "burned in" for a time period of approximately three weeks, to eliminate any premature electronic component failures. This is an excellent time to become familiar with the system, and conduct training classes for operators and craftsmen.

Installinq the System

Before the old system is shut down, much can be done. Determine how much of the new system can be checked out and what instruments can be mounted. Most of the conduit and wiring can be installed. Plan each installation activity so there is a minimum amount of lost time.

Another thing which cannot be overemphasized is verification of the wiring. Improper wiring can be a time consuming problem to resolve. The wiring should be checked from the control room junction box to the turbine deck junction box before any wire is connected to the control system, or any field device.

During the retrofit, all items not being used should be removed. In the course of earlier retrofits, items no longer needed such as tubing, valves, and piping were left in place. These items caused confusion, and ended up costing time and money during troubleshooting activities.

Next, the wiring from the turbine junction box to the valves, transmitters, and field contacts can be completed. Signals from the control room junction box now can be fed to the previously mentioned devices on the turbine deck, and proper operation verified. The control room junction box can be connected to the control system. Signals can be driven by the control system to the field devices. The valves should be checked for proper stroke, smoothness, and responsiveness. The pressure controller, temperature limit controller, and spark plugs should be checked for proper operation. The field contacts can also be verified to the control system. Now, a complete system simulation can be performed. The user should follow a complete system checkout list for the turbine. A properly performed system check-out will guarantee a successful firing of the turbine the first time.

The installation on the turbine deck required additional sensors and field contacts to provide redundancy. The rest of the retrofit was the same as for the analog to digital installation.

BENEFITS DERIVED FROM RETROFITTING

There are many benefits derived from the new digital computers which were not available with analog systems. Having a system which is completely redundant means the control system will be more reliable. Using digital computers, information can be scrutinized before taking action and causing a needless trip. Communication with other systems, such as process computers, is also possible.

Graphic trending of information can be displayed in color for easier interpretation. Logging alarm information with time and date, storing trending information on hard disk for historical recalls, and displaying schematic diagrams of lube oil systems, seal oil systems, and turbine trains are all available. Pages of operating values can be displayed instantly and updated while the turbine is running. Operating parameters can be changed at the touch of a button. The control system can be reconfigured with software changes rather than rewiring or circuit board changes.

Another feature available is the vote to trip. If a user has two healthy computers and a trip occurs, both computers must agree that it is real before the turbine is shut down. If one computer has failed, it will always vote to trip, leaving the final decision up to the one healthy computer. Once the defective computer has been repaired, it will then take both computers to trip the turbine.

Troubleshooting Aids

An advantage of the digital computer is the ease in troubleshooting the control system in the unlikelihood of a turbine trip. With analog, one of the hardest problems to live with is when the turbine trips for no apparent reason. After troubleshooting and replacing a suspected circuit board, the turbine is started, knowing the real reason for the trip may not have been found and the turbine could trip again.

The digital system reduced this problem to a thing of the past. It provides a trending system that can record as many items as required and do so about every five seconds. When a trip occurs, a bar graph is printed displaying the last five minutes of turbine operation. The telltale bar graph will confirm systems which are operating properly, or pinpoint the cause of the trip.

Another benefit of these systems is the way alarms are logged. Once an alarm occurs, it is annunciated in the usual manner and then printed out on a alarm printer along with the status, time, and date. It is recorded in the computer's memory, and can be called up for immediate review. If a trip occurs, the alarms leading up to it will be displayed. An additional benefit of the system is its ability to recall past trips, and see if there is a trend.

If a control computer fails, its self-diagnostics will display the problem, and indicate which control circuit board to change. The defective board is changed while the turbine is running, and the computer is brought back online.

Spare Parts

One of the most difficult areas to maintain is spare parts. There is nothing more exasperating than having a spare part, only to find it is defective. Electronic circuit boards are good examples.

This company has taken a different approach to parts storage and improved reliability. The company chose to purchase a complete backup system for the control computers. The idea is to keep the spare system running under simulation. This provides us proven circuit boards and parts to make a speedy and reliable repair if the control system fails. The computer boards require special training to repair. They are more difficult to repair than analog boards. If a board fails, time can be taken to repair the defective board, and install it in the backup system. Turbine operation can then be simulated to verify the repair corrected the problem. If a user stays with the same computer system, parts inventory will stay low. Whether a large or small system, the circuit boards are all similar with the only difference being the program memory chips.

Since the turbine will be down only on rare occasions, there is the problem of forgetting how to properly operate the control system. The simulator resolves this problem by allowing operators and maintenance technicians to train on it at any time. In addition, the simulator is an excellent test bed to try out new software changes before installing them in the operating system. Typical gas turbine simulators are shown in Figure 4.

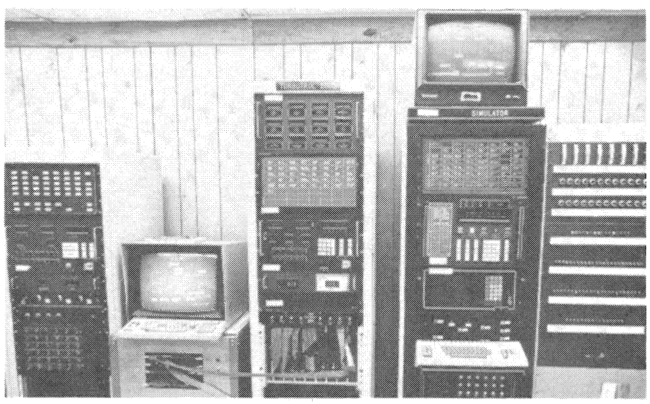

Figure 4. Typical Gas Turbine Simulators.

CONCLUSIONS

There are several options to improve operating reliability, from installing a new gas turbine and associated control equipment, to retrofitting the turbine with better controls. Since reduced maintenance costs and improved reliability are a prime factor, retrofitting the existing control system should be considered.

Successful retrofits require adequate planning, involvement of key personnel, proper system configuration, and detailed specifications. Good installation techniques, proper system check out, and adequate training ensure a reliable installation.

Redundant digital computer control systems have brought considerable improvements to turbine operating reliability by reducing downtime and improving maintainability of the equipment. In addition, machine reliability (mean time between failures) has been increased, trending of turbine parameters has been enhanced and troubleshooting capabilities improved. It is possible to make improvements to the existing turbomachinery control system and profit from the experience through retrofitting.

There are many specialized firms that can assist users in retrofitting. The user must take the lead in determining the basic requirements. The user also needs to be a contributing part of the redesign, installation, and startup of the new control system.

REFERENCE

1. Nelson, W. E., Wright, R. M., "Reengineering of Rotating Equipment Through Maintenance," 37th ASME Petroleum Mechanical Engineering Workshop and Conference, Dallas, Texas (September 1981).

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